DYNAMICS OF NATURAL SATELLITES OF PLANETS AND ASTEROIDS BASED ON OBSERVATIONS.

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The article presents the justification and results of the author's activity in creating means of modeling the motion of satellites of giant planets and satellites of asteroids. The necessity of this activity is due to the possibility of using planetary satellites as the most suitable places for landing spacecraft and expanding the human habitat. Therefore, it is necessary to calculate the position of satellites in space with the most excellent possible accuracy to get there with minor energy costs. It could be done by developing satellite motion models. Such models, also called ephemeris, are the result of studying the dynamics of these bodies since they are based on all our knowledge, including all available observations.The study of the dynamics of satellites by constructing models of motion is also a means of ensuring the familiarization of the solar system and the extraction of new fundamental knowledge. The result of the work was a database of observations of satellites of planets and a server of ephemeris of satellites. All are available to any user via the internet.

Keywords: Satellites of the planets – Ephemeris – Observations.

1. INTRODUCTION

The solar system, containing many large and small bodies, is a space - potentially possible to expand the human habitat. In their desire to develop new lands, Europeans stumbled across America. Before heading over there, it is better first to study the planets and satellites. Because outer space poses more dangers and uncertainties for a man than the open ocean, the question will inevitably arise in free flight between the planets: where to land? Then, of course, the planets will capture us with their gravity, but we will want to return to Earth. It should be

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taken enough rocket propellant to overcome the gravity of another planet. Flying back and forth requires much energy.

On the way there, we will see that the planets have satellites. They have less gravitation and are not far from the planet: observe it as much as possible. Furthermore, the satellite itself is interesting. What is it made of? Where did it come from? It is the best place to live away from Earth. To land on a satellite, one needs to aim well. However, satellite flies as it pleases. We will have to calculate the coordinates beforehand.

Moreover, if we are wrong? Will there be enough rocket fuel to correct the trajectory? No, it is better to study the dynamics of the satellite on Earth. It is necessary to learn how to calculate its motion. The satellite is far away, but we have computers here. It would be great if the satellite model were on the computer! Then study the dynamics as much as possible. However, the satellite in the computer must fly in the same way as it does in space. It should be necessary to observe from the Earth its behavior, i.e.,motion. Satellites are far away, but astronomers learned to see them and accurately measure their coordinates. Galileo, in 1610 saw the first 4 satellites of Jupiter. And it began. However, mainly very slowly at first. In 1950, people knew 30 satellites, and in 2000 - 70. Powerful new telescopes were built at the end of the twentieth century. What were they looking for? First, of course, the hazards of falling asteroids on Earth. It was actual. Sometimes it was impossible to determine the asteroid's orbit, and it turned out to be not an asteroid but a satellite of Jupiter or Saturn. Thus, many new satellites began to be discovered. And not only for Jupiter and Saturn but also for Uranus and Neptune. Now 209 satellites of the planets are known. Furthermore, now new ones are discovered.

It means that the satellite must fly in the computer as it does near the planet. For this, the motion should be measured. Astronomers have long been used to calling such measurements observations. Observations are carried out using telescopes. However, to accurately measure the position of a satellite in the sky, a telescope should have good cameras. Nowadays, they are CCD cameras. Measurements should be carried out as accurately as possible. To aim better at the satellite and have enough rocket propellant to return. Here we depend on telescope-developing technology and electronics. With this, things are moving slowly yet. The circumstances of the motion of satellites and other solar system bodies are such that the accuracy of coordinates precomputation on time points in the future depends on the time interval of observations.

The possible most extensive interval is needed. It is even necessary to use observations conducted before discovering the satellite. The French scientist Urbain Le Verrier had done just that. He understood in 1846 that the planet Uranus was not moving as his theory predicted. Instead, Le Verrier thought that Uranus was affected by the gravitation of some unknown planet. An observer familiar to him looked where Le Verrier pointed and discovered a new planet there. Later, it was named Neptune. Le Verrier was looking for a new planet on old photographic plates. Moreover, he found that what was previously taken for a star was a new planet precomputed by him. Nowadays, it is also worth looking for satellites on old photo plates to increase the maximum observation time interval necessary for us. As a result, it turns out that observations are the basis of our knowledge about the motion of planetary satellites-however, not just observations. Many things impact the motion of satellites. For example, there is a planet near the satellite that attracts it. The satellite even feels by its motion that the planet is not round. Nowadays, it is known that all giant planets are compressed at the poles.

Our spacecraft will be gravitated by the massive planet when approaching the satellite. We need to know the planet's mass to calculate the trajectory. Where get it? The planet cannot be weighed on a scale. Let spacecraft fly there. Let us determine the planet's mass from the deviations of their trajectories. However, this is very expensive. Well, the satellites of the planet therein fly wholly free. Let us measure their motion. In former times, the planets′ masses were determined only by the motion of satellites. So, we can determine the mass of the planet and its compression. The compression of the planet also impacts the motion of satellites. That is not all. There is also the Sun. It is very far away but very massive. The Sun's gravity should be considered in the motion of the satellite. As a rule, the satellite of the planet is not one. All satellites gravitate to each other. It also should be considered. As a result, the theories of the motion of planetary satellites turn out to be the most complex in celestial mechanics.

But, back to observations. These data will make the satellite model in the computer move in the same way. All observations that have been conducted around the world are necessary. It was evident not only to the author. In 1996 our French colleagues invited the author to Paris to collect a database of satellite observations. We looked for observations everywhere.
For example, in the Kazan City Astronomical Observatory's writings and such an old "exotic" publication as "Manuscripts deposited at VINITI." Therefore, it was necessary to collect data and organize a database and even provide access to it via the internet.

It was done to any colleagues in the world who could benefit from our papers' results. There is no other suchlike database in the world. Moreover, the message about creating the database was published in a high-rated scientific journal [1].

Thus, by compiling huge computational programs, it was possible to make the satellites move in the computer in the most similar way as they move around the planet. So it is for all known 209 satellites of the giant planets from Mars to

Pluto.

Undoubtedly, we are interested in using models of satellite motion for everyone who needs it. Nowadays, this is done by creating so-called ephemeris servers on the internet. We created such a server. Accordingly, this was published in a high-rated scientific journal [2]. Such servers have only Americans (JPL, California Institute of Technology), and options that are very limited in terms of satellite composition are at the International Minor Planet Center (MPC) and Institute of Applied Astronomy of the Russian Academy of Sciences (RAS). Our ephemeris server for all satellites of the planets called MULTI-SAT is available on the website of the GAISh MSU at the address: http://www.sai.msu.ru/neb/nss/indexr.htm. A so-called mirror of these pages is hosted on the website of the French Institute of Celestial Mechanics and Ephemeris Computation (IMCCE) at http://nsdb.imcce.fr/multisat/. The French colleagues have no other such server with satellites. The MULTI-SAT ephemeris server makes it possible to calculate the ephemerides of the Moon and the Sun simultaneously. As for the satellites of minor planets, namely asteroids, the situation is more egregious.

At present are known about 250 asteroids that have satellites. About all satellites we know are that they exist. Asteroid satellites are separated from their main bodies by the interval of no more than a 1-second arc. It is very complicated to measure differential coordinates under such conditions. It requires adaptive optics to compensate for image jitter due to light refraction in the Earth's turbulent atmosphere. The ingenious method of speckle interferometry is also applied. Otherwise, the coordinates cannot be measured in any way. Various authors were able to determine the orbits of asteroid satellite.
At one time, the American V. Grundy and his colleagues succeeded. They determined the orbits of 38 satellites [3, 4]. For these reasons, there are very few observations of satellites of asteroids. All of them are collected in our unique database. Accordingly, it is published in [5]. Under these conditions, the author set to work. It was possible to determine the orbits of 64 satellites of asteroids. It is the maximum that can be done from the available astrometric observations. All of these ephemerides are included in the server MULTI-SAT. The message was published in the international scientific journal Icarus [6].
Knowing the orbits of asteroid satellites gives us the value of the total mass of the principal component with the satellite. It is almost the only way to determine the mass. Another way - launch a spacecraft to fly past. The mass also can be determined by measurements of the apparatus's deviations due to the asteroid's gravitation.

However, this is very expensive. When determining the orbit of the satellite Linus of the asteroid Kalliope, an unresolved mystery arose. The observations of this satellite were carried out at the Caucasian Mountain Observatory of the GAISH MSU. We have collected quite a few observations of this satellite with other previous observations on a long-time-interval. Thus, this made it possible to determine the extension of the principal component.

Since the asteroid rotates rapidly, its gravitational field impacts the satellite as the field of a compressed body. Because of this action, the satellite's orbit must precess in the counter direction concerning the satellite's orbital motion. However, the determination of the orbit from observations shows the opposite, a direct precession of the orbit. Jointly with the GAISH observers, our message about this unexplained effect was published in a high-rated scientific journal [7]. Regarding this riddle, we have only hypotheses.

As noted above, the success of observations and modeling of satellite motion depends on progress in telescope optics and electronics. However, some practitioners of celestial mechanics were not expecting gifts from this but looking for new ways to obtain positional data on planetary satellites. It turns out that the orbits of some of the principal satellites of the planets lie approximately in the same plane, inclined to the plane of the planet's orbit. For this reason, when observing from the Earth, satellites can cover (obscure) each other. In addition, during these periods, one satellite can fall into the shadow of another. In this case, the total brightness of the satellites decreases.
The decrease can be measured by observing satellites from Earth. Furthermore, by measured light curve can be determined the differences in satellite coordinates. The accuracy of such determinations is better than that of conventional astrometric observations. Phenomena occur within 9-15 months once in half-turn of the planet around the Sun.

For the satellites of Jupiter, this is once every six years. The duration of mutual covering or mutual eclipse is 5-15 minutes. Such short-term phenomena simultaneously can be observed only at a part of ground-based observatories. Therefore, international campaigns for such observations are organized. The processing of satellite photometry during these mutual events, namely, obtaining the mutual coordinates of the satellites by the light curve, is a very complex process.

An original method was developed for this by the author. As a result, the observations of all international campaigns from 2003 to 2021 were processed by the author in the GAISH. The obtained results were published in a high-rated journal, and all theparticipated observers in the observations became co-authors of the article. See publication [8] and references to the bibliography in this article. As a result, highaccurate positional data were obtained. Together with other observations of the satellites, these data allowed the french colleagues to determine the parameters of the viscosity of the matter of the satellites [9, 10]. These results allowed us to explain some of the past mysteries in the motion of satellites. In solving the problems described in the present article, original findings and achievements appeared.

Let us look at a couple of the most significant of them. When modeling the motion of distant satellites of Jupiter, a unique opportunity arose to determine the mass of one of the satellites of Himalia by its gravitational impact on some other satellites. This influence was reflected in the results of observations. Before that, the mass of satellites was found from measurements of their brightness with the acceptance of several uncertain hypotheses about the properties of the surface and the density of the matter of the satellites. The mass value obtained by the author significantly differed from the value published in handbooks.

It was done in 2005 [11]. Only 12 years later, the found value of the mass of Himalia was confirmed in the work of American colleagues [12].When publishing and using ephemerides of celestial bodies, one rarely thinks about the accuracy of ephemerides.

However, the issue of the accuracy of the ephemeris of the distant satellites of the giant planets is considered by the author. Three methods for assessing accuracy were developed [13]. Accuracy estimates conducted in 2010 showed that the accuracy of the ephemeris of some satellites is half-turn of the satellite around the planet. That is, satellites can be considered lost. Such conclusions were made for 21 satellites of Jupiter. Later in 2012, the conclusions about the loss of satellites were confirmed in the work of American colleagues [14]. They carried out new observations and found some of the lost satellites, but not all. All developed methods and solutions obtained by the author are collected in the book [15]. The book was translated into English and published by Elsevier's international publishing house [16].

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